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(54) **APPARATUS AND CIRCUIT HAVING
REDUCED LEAKAGE CURRENT AND
METHOD THEREFOR**

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(58) **Field of Search** **257/368, 369,**
257/370; 327/534, 535; 365/185.14

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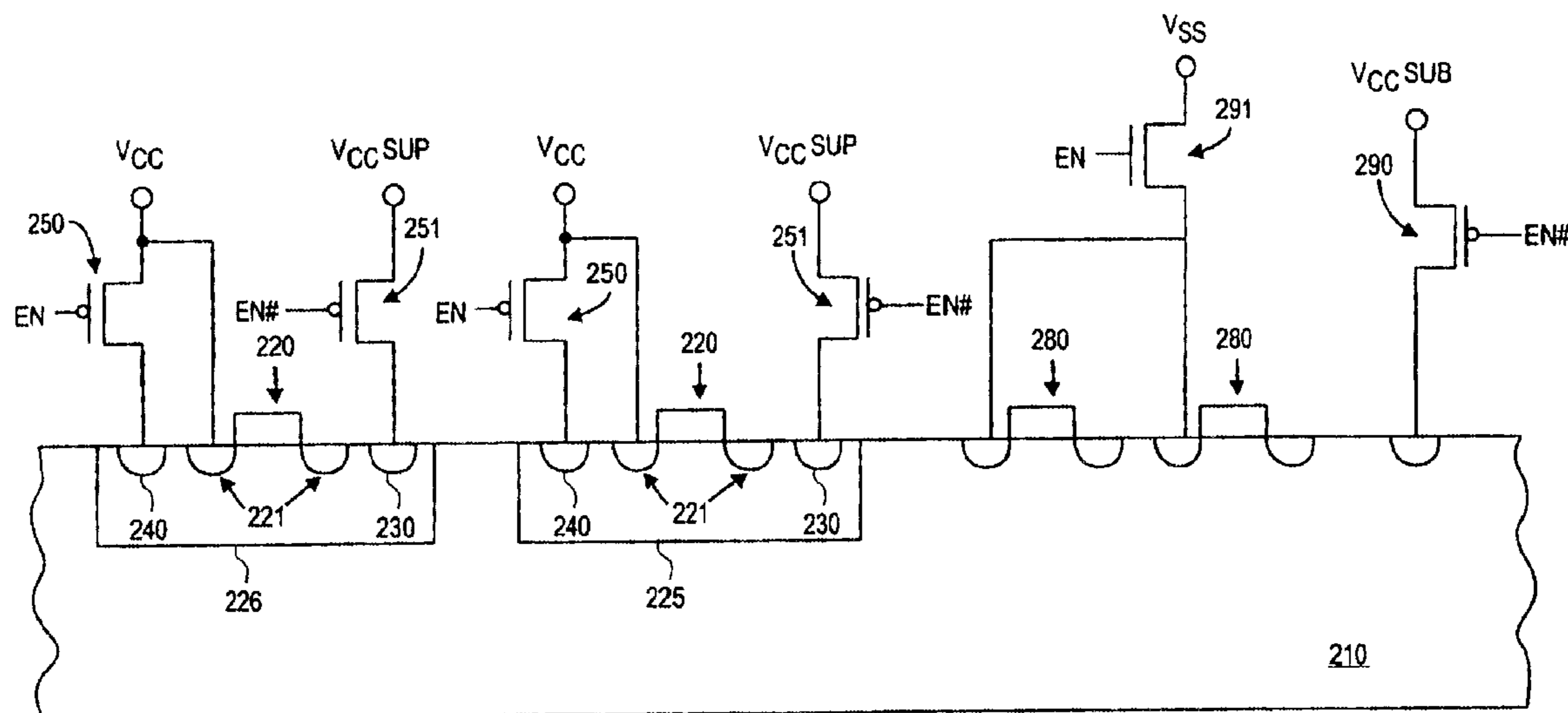
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(57) **ABSTRACT**

Briefly, in accordance with one embodiment of the invention, an integrated circuit has a voltage generator that selectively increases the voltage potential on the channel region of a transistor relative to the source region of the transistor. The voltage potential may be provided to a diffusion region in the well regions with transistors.

21 Claims, 3 Drawing Sheets



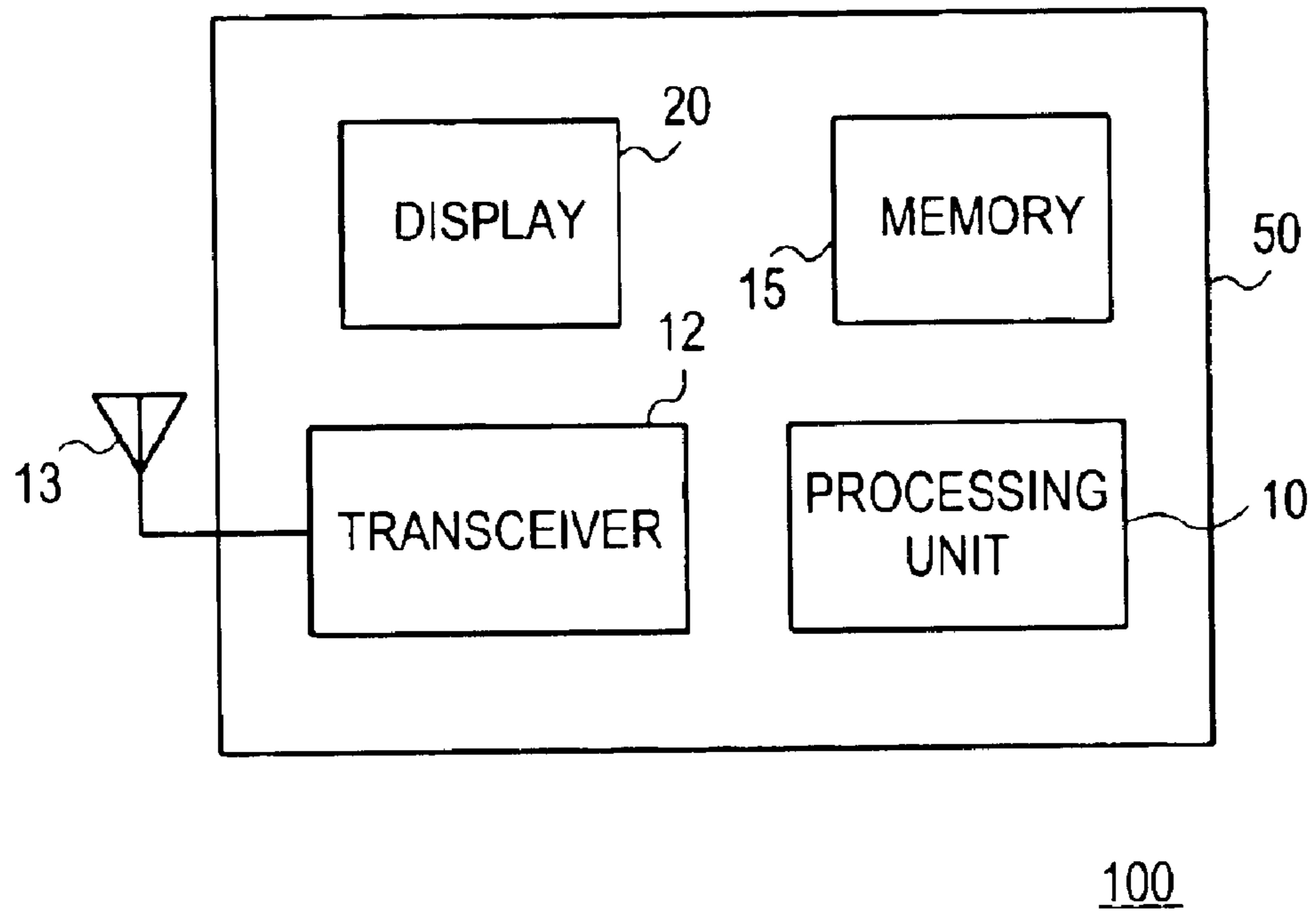


FIG. 1

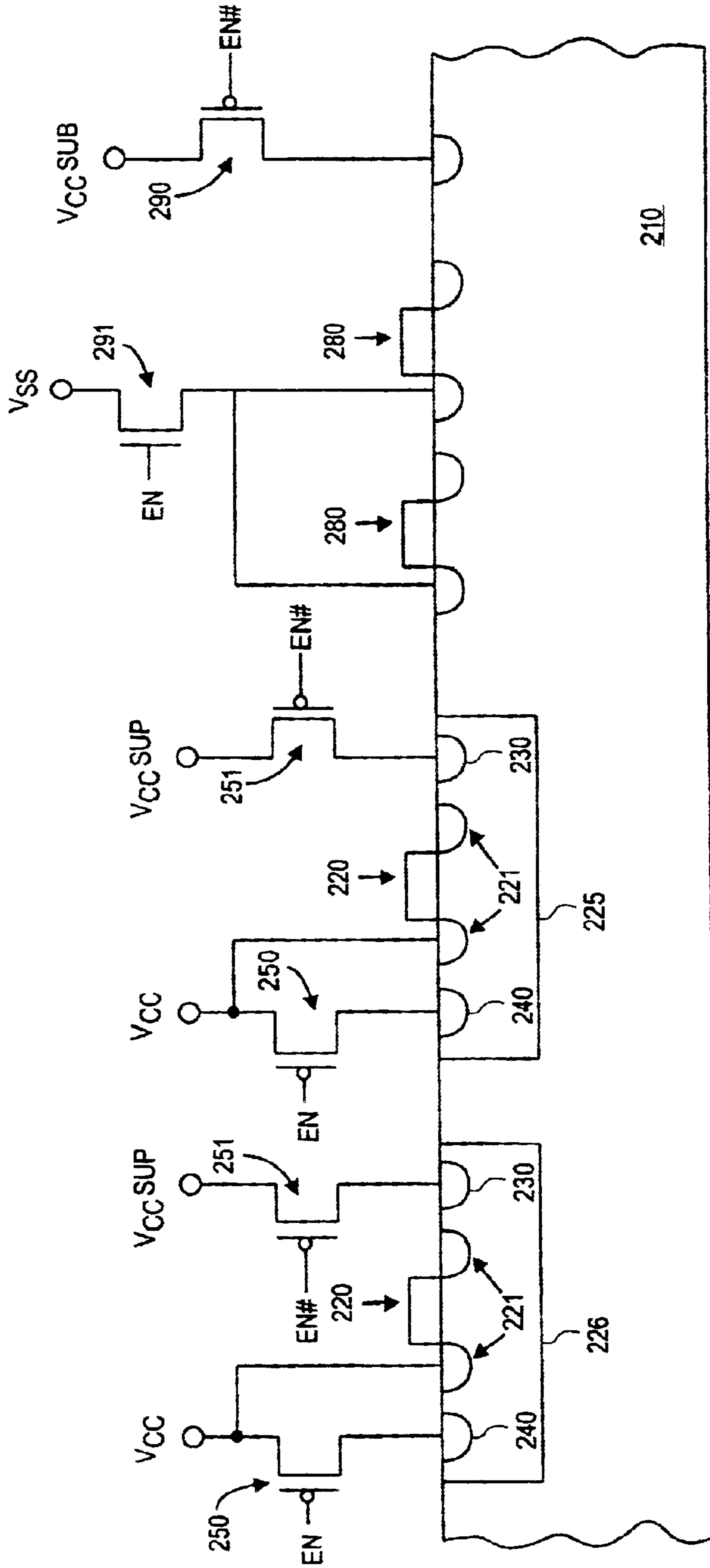


FIG. 2

APPARATUS AND CIRCUIT HAVING REDUCED LEAKAGE CURRENT AND METHOD THEREFOR

BACKGROUND

Advances in manufacturing techniques have allowed transistors to be made with smaller geometries. For example, photolithographic and etch techniques have improved to the point where transistors with a gate length of less than 0.10 microns (μm) may be made. Decreasing the size of transistors is generally perceived to be beneficial because this may allow more transistors to be made within the same amount of area on a semiconductor die.

However, as the gate length of a transistor is reduced, the distance between the current carrying electrodes (e.g., source and drain terminals) may also be proportionately reduced. Consequently, the amount of semiconductor material between these terminals and beneath the gate of the transistor, often referred to as a channel or body region, may be reduced. As the length of the channel region of a transistor is reduced, the electric field of the drain terminal may have a greater effect upon the flow of current in the channel region. Thus, reductions in channel length may make it more difficult to control the flow of current across the channel region between the source and drain terminals and lead to an increase in the amount of source-to-drain leakage (e.g., off-state current).

Techniques to address this leakage current may involve applying a voltage potential to the bulk or channel region when the transistors are inactive. However, such techniques often involve the use of additional metal lines that are routed across an integrated circuit to provide the leakage reducing voltage potential. This, in turn, may increase the complexity and cost of the manufacturing process. Thus, there is a continuing need to reduce the leakage current between the current carrying electrodes of transistors.

BRIEF DESCRIPTION OF THE DRAWINGS

The subject matter regarded as the invention is particularly pointed out and distinctly claimed in the concluding portion of the specification. The invention, however, both as to organization and method of operation, together with objects, features, and advantages thereof, may best be understood by reference to the following detailed description when read with the accompanying drawings in which:

FIG. 1 is a block diagram of a computing system in accordance with an embodiment of the present invention;

FIG. 2 is a cross-sectional representation of transistors in accordance with an embodiment of the present invention; and

FIG. 3 is a schematic representation in accordance with an alternative embodiment of the present invention.

It will be appreciated that for simplicity and clarity of illustration, elements shown in the figures have not necessarily been drawn to scale. For example, the dimensions of some of the elements may be exaggerated relative to other elements for clarity. Further, where considered appropriate, reference numerals may be repeated among the figures to indicate corresponding or analogous elements.

DETAILED DESCRIPTION

In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of the invention. However, it will be understood by

those skilled in the art, that the present invention may be practiced without these specific details. In other instances, well-known methods, procedures, components and circuits have not been described in detail so as not to obscure the present invention. Note, in this description a “#” symbol is used to indicate the logical complement of a signal. For example, if BL is a logic “1,” then BL# is a logic “0,” although this invention is not limited to any particular signaling scheme.

In the following description and claims, the terms “coupled” and “connected,” along with their derivatives, may be used. It should be understood that these terms are not intended as synonyms for each other. Rather, in particular embodiments, “connected” may be used to indicate that two or more elements are in direct physical or electrical contact with each other. “Coupled” may mean that two or more elements are in direct physical or electrical contact. However, “coupled” may also mean that two or more elements are not in direct contact with each other, but yet still co-operate or interact with each other.

It should be understood that embodiments of the present invention may be used in a variety of applications. Although the present invention is not limited in this respect, the circuits disclosed herein may be used in many apparatuses such as in the transmitters and receivers of a radio system. Radio systems intended to be included within the scope of the present invention include, by way of example only, cellular radiotelephone communication systems, satellite communication systems, two-way radio communication systems, one-way pagers, two-way pagers, personal communication systems (PCS), personal digital assistants (PDA's) and the like.

Types of cellular radiotelephone communication systems intended to be within the scope of the present invention include, although not limited to, Code Division Multiple Access (CDMA) cellular radiotelephone communication systems, Global System for Mobile Communications (GSM) cellular radiotelephone systems, North American Digital Cellular (NADC) cellular radiotelephone systems, Time Division Multiple Access (TDMA) systems, Extended-TDMA (E-TDMA) cellular radiotelephone systems, third generation (3G) systems like Wide-band CDMA (WCDMA), CDMA-2000, and the like.

Turning to FIG. 1, an embodiment **100** in accordance with the present invention is described. Embodiment **100** may comprise a computing system **50** such as, for example, a portable device such as a mobile communication device (e.g., cell phone), a two-way radio communication system, a one-way pager, a two-way pager, a personal communication system (PCS), a portable computer, or the like. Although it should be understood that the scope and application of the present invention is in no way limited to these examples.

Computing system **50** here includes a display **20** to provide information to a user, a memory **15**, and a processing unit **10** that may comprise one or more integrated circuits, although the scope of the present invention is not limited in this respect. Processing unit **10** may comprise, for example, a microprocessor, a digital signal processor, a microcontroller, or the like. Simply stated, processing unit may be used to execute instructions to provide information or communications to a user. Instructions to be executed by processing unit may be stored in memory **15**, although the scope of the present invention is not limited in this respect.

Memory **15** may comprise, for example, disk including floppy disks, optical disks, CD-ROMs, magnetic-optical

disks, read-only memories (ROMs), random access memories (RAMs) such as dynamic RAM (DRAM) or static RAM (SRAM), electrically programmable read-only memories (EPROMs), electrically erasable and programmable read only memories (EEPROMs), a flash memory array, magnetic or optical cards, or any other type of media suitable for storing electronic instructions.

Computing device **50** may also include a transceiver **12** and an antenna **13** to provide wireless communication with other devices. Although the scope of the present invention is not limited in this respect, transceiver **12** may permit computing device **50** to communicate using one of the communication standards listed above. Alternatively, computing device **50** may include hardware to permit computing device **50** to communicate with or as part of a wireless local area network (WLAN).

Turning to FIG. 2, a portion of an integrated circuit **200** that may be used to provide a portion of processing unit **10** (see FIG. 1) is described. FIG. 2 is a combination of a cross section of a portion of a semiconductor substrate **210** in which portions of transistors **220** and **280** may be formed. In addition, portions of a circuit schematic have been added to illustrate how power supply voltage potentials may be applied to various portions of semiconductor substrate **210** to reduce the leakage currents within semiconductor substrate **210**.

Although the scope of the present invention is not limited in this respect, semiconductor substrate **210** may be doped p-type in which well regions **225** and **226** may be formed with an n-type dopant. Well regions **225** and **226** may contain portions of p-channel metal oxide semiconductor (PMOS) transistors **220** (i.e. well regions **225–226** may contain current carrying electrodes **221**, such as source and drain regions, along with the corresponding channel region between the current carrying electrodes). Transistors **220** may be connected as desired to provide the logic operations or other circuitry of processing unit **10**. Further, it should be understood that FIG. 2 may only illustrate a small portion of processing unit **10** and that semiconductor substrate **210** may comprise additional well regions and PMOS transistors. Alternatively, the conductivity type of substrate **210** and/or well regions **225–226** may be altered as desired.

Well regions **225** and **226** may further include a doped or diffusion region, such as diffusion regions **241** and **240**, respectively. Although the scope of the present invention is not limited in this respect, doped regions **240–241** may be doped to an n-type conductivity and may be used to bias portions of well regions when transistors **220** are inactive or in a disabled operational mode. Diffusion regions may be formed by introducing an n-type dopant into a portion of well regions **225–226**. Although the scope of the present is not limited in this respect, diffusion regions **240–241** may be formed using an ion implantation process.

Integrated circuit **200** may have a variety of operational modes; some of which may be used to reduce the amount of power consumed by computing device **50**. For example, although the scope of the present invention is not limited in this respect, integrated circuit **200** may have an active mode during which transistors **220** may be used and an inactive operational mode during which transistors **220** may not be needed. Although the scope of the present invention is not limited in this respect, in one particular embodiment, the active mode may represent a condition during which computing device **50** may be in use by a user whereas the inactive mode may occur if the user turns computing device **50** off or places computing device **50** in a stand-by, low

power mode. When in the low power operational mode, computing device **50** may halt or slow down the execution of instructions in an attempt to reduce its power consumption. While in this operational mode, the power supply potentials may be applied to transistors **220** so that the volatile logic value is not lost or changed during this operational mode. Consequently, the data or logic value stored in transistors **220** may be used when computing device **50** again changes operational modes and begins executing instructions.

In the inactive mode, it may be desirable to apply a voltage potential to wells **225–226** that is greater than the voltage potential of the current carrying electrodes of transistors **220**.

In the particular embodiment shown in FIG. 2, integrated circuit **200** may include transistors **250–251** that may be used to provide power supply voltage potentials of portions of wells **225–226** and transistors **220**. In the particular embodiment shown in FIG. 2, the source of transistors **250** is directly connected to diffusion regions **240**. However, the scope of the present invention is not limited in this respect. In alternative embodiments, the source of transistors **250** may be shared with diffusion regions **240**, or alternatively, additional circuitry may be inserted there between to couple transistors **250–251** to well regions **225–226**.

As shown in the particular embodiment of FIG. 2, although the scope of the present invention is not limited in this respect, a control or enable signal, labeled EN in FIG. 2 as “EN”, may be used to control or indicate when integrated circuit **200** is in a low power mode such as drowsy, stand-by, sleep, etc. Although the scope of the present invention is not limited in this respect, the enable signal, EN, may be an active high signal. However, in alternative embodiments, an active low signal may be used with the associated changes in the transistors used. Thus, the control signal EN may be used to indicate when PMOS transistors **220** are to be placed in the disabled operational mode.

For example, when transistors **220** are active or in use, a power supply voltage potential, labeled Vcc, may be applied to the a current carrying electrode (e.g. a drain terminal) of transistors **220**. In addition, the control signal EN may be deasserted so as to allow transistors **250** to provide approximately the same power supply voltage potential to well regions **225–226**. It should be noted in this particular embodiment, transistors **251** are not enabled (e.g. they are turned off).

When a portion of integrated circuit **200** is to enter an inactive or disabled operational mode, the control signal EN may be asserted. This in turn may enable transistor **251** so that transistor **251** may provide diffusion region **230** with another power supply voltage potential, namely Vccsub. In this particular embodiment Vccsub is greater than Vcc. For example, although the scope of the present invention is not limited in this respect, Vccsub may be approximately 0.2–0.9 volts greater than Vcc.

Thus, diffusion region **230** may be used to provide a higher voltage potential to well regions **225–226**, and, in turn, a higher voltage potential to the channel region of transistors **220** than that of the drain terminal of transistors **220**. This may reduce the amount of leakage current and/or power consumption of integrated circuit **200**. It should be noted that when the control signal EN is asserted, transistor **250** may be deasserted thereby disconnecting diffusion region **240** from the Vcc power supply voltage potential.

In alternative embodiments of the present invention, although not necessarily all, it may be desirable to include

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addition diffusion regions that may be coupled to the V_{cc} power supply voltage potential with transistors. These addition diffusion regions may be spaced throughout well regions 225–226 as desired and the control signal EN may be used to control the application of the V_{cc} power supply voltage potential to well regions 225–226 as described above.

As shown in FIG. 2, integrated circuit 200 may also optionally include n-channel metal oxide semiconductor (NMOS) transistors 280 that may be used independently or in conjunction with transistors 220 to provide logic operations while computing device 50 is in operation. NMOS transistors 280 may include current carrying electrodes 281 (e.g. source and drain regions that may be formed in semiconductor substrate 210. In addition, integrated circuit 200 may include transistors 290–291 that may be used to reduce the leakage currents associated with transistors 280. For example, transistors 291, controlled by control signal EN, may be used to provide a power supply voltage potential V_{ssub} to semiconductor substrate 210. Since transistors 280 are NMOS transistors, it may be desirable to have V_{ssub} be less than the V_{ss} power supply voltage potential that is applied to the drain terminals of transistors 280.

Thus, when the control signal EN is asserted to indicate transistors 280 are to enter a disabled operational mode, transistor 290 may provide a voltage potential to the channel region of transistors 280 so that the leakage current associated with transistors 280 may be reduced. In one particular embodiment, integrated circuit 200 may include a regulator (not shown) that may provide the V_{ss} power supply voltage potential that is about 0.2–0.9 volts greater than the V_{ssub} voltage potential when integrated circuit 200 is in a disabled operational mode. In addition, the regulator may optionally adjust the V_{ss} and V_{ssub} power supply voltage potentials so that they are substantially equal when integrated circuit 200 is in an active operational mode.

Turning to FIG. 3 a particular embodiment for providing some of the power supply voltage potentials is provided, although the scope of the present invention is not limited in this respect. In this particular embodiment, it may be desirable to assume that the V_{cc} power supply voltage potential is no more than a threshold voltage potential (V_{tp}) of transistor 301 from the V_{ccsub} voltage potential (i.e. V_{cc} is equal to or less than V_{ccsub} by no more than the threshold voltage of transistor 301). Similarly, it may be desirable to assume that the V_{ss} power supply voltage potential is no more than a threshold voltage potential of transistor 304 above the V_{sssub} voltage potential. In this particular arrangement, the circuit shown in FIG. 3 may be self regulating, although the scope of the present invention is not limited in this respect.

As shown in FIG. 3, when the control signal EN is asserted, transistors 301–302 may be turned off and transistor 303 may be turned on. This will in turn cause the voltage on the gate of transistor 304 to go to V_{ss} . In this state, the circuit will regulate V_{cc} to be roughly $V_{ccsub} - V_{tp}$ and V_{ss} to be roughly $V_{ss} + V_{tn}$. This biasing regulation may reduce the leakage in all transistors whose power is supplied by this circuit.

By now it should be appreciated that the present invention provides circuits and methods by which the leakage current of an integrated circuit may be reduced. In particular embodiments, although not necessarily all, each well region may have a diffusion region that may be coupled to a power supply voltage potential when transistors in the well region are to enter a low power mode. The reverse biasing of the

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channel or body region relative to the current carrying electrodes may increase the potential barrier created by the channel region. Consequently, this may make it more difficult for electrons to pass between the current carrying electrodes of the transistor.

While certain features of the invention have been illustrated and described herein, many modifications, substitutions, changes, and equivalents will now occur to those skilled in the art. For example, in alternative embodiments the conductivity of transistors may be changed to the opposite type. In addition, in some embodiments a diffusion region was used to provide electrical contact to well regions. In alternative embodiments other techniques may be used such as contacts, metal contacts, etc. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.

What is claimed is:

1. An apparatus comprising;

a semiconductor substrate having a first well region and a second well region in which at least a portion of p-channel metal oxide semiconductor (PMOS) transistors are formed;

a first diffusion region in the first well region;

a second diffusion region in the second well region;

a first transistor to couple the first diffusion region to a first power supply voltage potential when the PMOS transistors are in a disabled operational mode; and

a second transistor to couple the second diffusion region to the first power supply voltage potential when the PMOS transistors are in a disabled operational mode.

2. The apparatus of claim 1, wherein the first transistor and the second transistor include a gate terminal to receive a control signal that indicates the PMOS transistors are in the disabled operational mode.

3. The apparatus of claim 1, further comprising:

a third diffusion region in the first well region; and

a third transistor to couple the third diffusion region to the first power supply voltage potential when the PMOS transistors are in a disabled operational mode.

4. The apparatus of claim 3, further comprising:

a fourth diffusion region in the second well region; and a fourth transistor to couple the fourth diffusion region to the first power supply voltage potential when the PMOS transistors are in a disabled operational mode.

5. The apparatus of claim 1, further comprising:

a third diffusion region in the first well region of the semiconductor substrate; and

a third transistor to couple the third diffusion region to a second power supply voltage potential when the PMOS transistors are in an active operational mode.

6. The apparatus of claim 5, wherein the second power supply voltage potential is less than the first power supply voltage potential.

7. The apparatus of claim 5, wherein the PMOS transistors comprise a current carrying electrode that is coupled to the second power supply voltage potential when the PMOS transistors are in the active operational mode.

8. The apparatus of claim 1, wherein the first transistor has a first current carrying electrode that is directly connected to a conductor to provide the first power supply voltage potential, and the first transistor has a second current carrying electrode that is directly connected to the first diffusion region.

9. The apparatus of claim 8, wherein the second transistor has a first current carrying electrode that is directly con-

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nected to a conductor to provide the first power supply voltage potential and a second current carrying electrode that is directly connected to the second diffusion region.

10. The apparatus of claim **1**, wherein the semiconductor substrate includes another region in which at least a portion of n-channel metal oxide semiconductor (NMOS) transistors are formed, the semiconductor substrate including a third diffusion region, and wherein the apparatus further comprises a third transistor to couple the third diffusion region to a second power supply voltage potential when the NMOS transistors are in the disabled operational mode.

11. The apparatus of claim **10**, wherein the NMOS transistors include a drain region to be coupled to a third power supply voltage potential, the second power supply voltage potential being less than the third voltage potential when the NMOS transistors are in the disabled operational mode.

12. The apparatus of claim **11**, wherein the second power supply voltage potential is substantially equal to the third power supply voltage potential when the NMOS transistors are in an active operational mode.

13. The apparatus of claim **11**, wherein the first transistor and the second transistor comprise a gate terminal to receive a control signal, and the third transistor comprises a gate terminal to receive a logical complement of the control signal.

14. A system comprising:

a flash memory array; and

a processor coupled to the flash memory array, the processor comprising:

a semiconductor substrate having a first well region and a second well region in which at least a portion of p-channel metal oxide semiconductor (PMOS) transistors are formed, the first well region including a first diffusion region and the second well region including a second diffusion region;

a first transistor to couple the first diffusion region to a first power supply voltage potential when the PMOS transistors are in a disabled operational mode;

a second transistor to couple the second diffusion region to the first power supply voltage potential when the PMOS transistors are in the disabled operational mode.

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15. The system of claim **1**, further comprising:

a third diffusion region in the first well region;

a fourth diffusion region in the second well region;

a third transistor to couple the third diffusion region to the first power supply voltage potential when the PMOS transistors are in the disabled operational mode; and

a fourth transistor to couple the fourth diffusion region to the first power supply voltage potential when the PMOS transistors are in the disabled operational mode.

16. The system of claim **15**, wherein the first transistor, the second transistor, the third transistor, and the fourth transistor include a gate terminal to receive a control signal that indicates if the PMOS transistors are in the disabled operational mode.

17. The system of claim **15**, further comprising:

a fifth diffusion region in the first well region of the semiconductor substrate; and

a fifth transistor to couple the fifth diffusion region to a second power supply voltage potential when the PMOS transistors are in the disabled operational mode.

18. The system of claim **17**, wherein the second power supply voltage potential is less than the first power supply voltage potential.

19. A method of putting at least a portion of an integrated circuit into standby mode comprising:

providing a first power supply voltage potential to a plurality of well regions in a semiconductor substrate by enabling a plurality of transistors, each of the plurality of well regions being coupled to at least one of the plurality of transistors.

20. The method of claim **19**, wherein providing a first power supply voltage potential includes providing a first power supply voltage potential to a diffusion region in each of the plurality of well regions.

21. The method of claim **19**, wherein providing a first power supply voltage potential to a plurality of well regions includes providing the first power supply voltage regions to at least three well regions in the semiconductor substrate.

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